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Multuser Detection Employing a Novel Genetic Algorithm for UWB Communications

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Abstract

In this paper, a differential multuser detection (MUD) method using a novel genetic algorithm (GA) based on complementary error function mutation (CEFM) is employed for ultra-wideband (UWB) systems. The proposed MUD method, which combines a novel GA based on CEFM, is termed CEFM-GA for short. We describe the schemes of the CEFM-GA, analyze their algorithms and compare their computational complexity with other MUDs. Simulation results show a significant bit error rate (BER) performance gain can be achieved by employing the proposed CEFM-GA compared with successive interference cancellation (SIC), parallel interference cancellation (PIC) and conventional GA for UWB systems in lognormal fading channel.

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1. Introduction

With the recent increasing demand for short-range and high data transmission rates in wireless communications, a new generation of broadband wireless communication systems, namely ultra-wideband (UWB) systems has been developed in recent years[1].

Interest in the study of UWB systems has increased, especially the development of multuser detection (MUD) techniques in such systems. The optimal multuser detector proposed was very complex and too expensive to handle. So suboptimal detectors have become a focus of research[2]. When using suboptimal detection techniques in UWB systems, the bit error rate (BER) of the system is still high.

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Thus, exploiting intelligent computation techniques would seem to be a better approach. Genetic algorithm (GA) is the most popular method for engineering optimization.

In this paper, we propose a MUD method based on a novel GA with complementary error function mutation (CEFM) for UWB systems in lognormal fading channel. Compared with conventional GA [3] multiuser detectors in UWB systems, our novel GA, which is based upon CEFM, improves mutation process to achieve a better BER performance.

2. System model

In this section, we consider a K users model for a synchronous DS-UWB communication system over indoor multipath channel, where each user uses unique spreading sequence. The transmitted signal generated by the k th user is given by

$$x_k(t) = \sqrt{E_k} b_k s_k(t) \quad (1)$$

where E_k is the k th user's signal energy per bit, b_k is the k th user's data modulated by binary phase shift keying (BPSK), and $s_k(t)$ is the k th user spreading waveform which is given by

$$s_k(t) = \frac{1}{\sqrt{N_s}} \sum_{i=1}^{N_s} c_k(i) p(t - iT_c) \quad (2)$$

Finally, the total received signal can be obtained by

$$r(t) = \sum_{k=1}^K x_k(t) \otimes h_k(t) + n(t) \quad (3)$$

where \otimes denotes linear convolution and $n(t)$ is zero-mean additive white Gaussian noise (AWGN).

3. Genetic algorithm based on complementary error function mutation (CEFM-GA)

GA is a probabilistic search technique based on the principle of biological evolution. GA uses probabilistic transition rules to select someone to reproduce or to die so as to guide their search toward regions of the search space with likely improvement. Thus, a GA is a powerful and globally stochastic search and optimization technique, and is widely employed in optimization problems of industrial engineering.

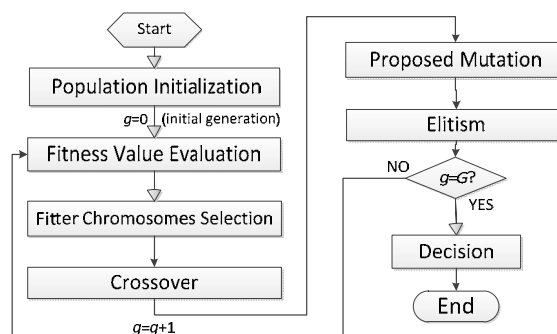


Fig. 1 The flow chart of the proposed CEFM-GA assisted multiuser detection scheme for UWB system

Firstly, we define the trial data vector in our proposed GA based on CEFM MUD as $\hat{\mathbf{b}} = [\hat{b}_1, \hat{b}_2, \dots, \hat{b}_K]^T$ for K users. Then

$$\hat{r}(t) = \sum_{k=1}^K \sqrt{E_k} \hat{b}_k s_k(t) \otimes h_k(t) \quad (4)$$

represents the estimated value of the received signal $r(t)$ for K users.

Fig. 1 shows a flow chart of the proposed CEFM-GA assisted MUD used in the UWB system. After our proposed CEFM-GA MUD process, the trial datum \hat{b}_k will be the optimum or near- optimum estimated value of the b_k in (1) for the k th user.

For the purpose of succinctness, we will simply describe the philosophy of the proposed CEFM-GA.

3.1. Start with encoding and Population initialization

For the start of the GA, the trial data vector $\hat{\mathbf{b}}$ must first be encoded into binary string form. The encoded binary string is regarded as a chromosome in GA and its elements are regarded as genes. Thus, the MUD can be treated as a multi-objective optimization solution that finds the most likely combination of the binary bits [4].

In our proposed GA, each individual or chromosome in the population is represented by a vector including K bits. In the vector, each bit is a trial datum belonging to one of the K users. The p th individual which is the estimated value of $\mathbf{b} = [b_1, b_2, \dots, b_K]^T$ in (1) is defined as

$$\hat{\mathbf{b}}_p^{(g)} = [\hat{b}_{1,p}^{(g)}, \hat{b}_{2,p}^{(g)}, \dots, \hat{b}_{K,p}^{(g)}]^T \quad p = 1, \dots, P \quad (5)$$

where superscript g denotes the g th generation ($g = 1, \dots, G$), and $\hat{b}_{k,p}^{(g)}$ denotes the k th ($k = 1, \dots, K$) gene of the p th individual at the g th generation.

3.2. Fitness evaluation

The solution of optimum detection dictates that the most likely trial data vector $\hat{\mathbf{b}}_{opt}$ minimizes, consider the likelihood function, we choose the fitness evaluation as

$$\begin{aligned} \Omega(\hat{\mathbf{b}}) &= 2 \int_{T_s} \left(\sum_{k=1}^K \hat{b}_k S_k(t) \right) \left(\sum_{k=1}^K \sqrt{E_k} b_k s_k(t) \otimes h_k(t) + n(t) \right) dt - \int_{T_s} \left(\sum_{k=1}^K \hat{b}_k S_k(t) \right)^2 dt \\ &= 2\hat{\mathbf{b}}^T \mathbf{S} \mathbf{S}^T \mathbf{b} + 2\hat{\mathbf{b}}^T \mathbf{n} - (\hat{\mathbf{b}}^T \mathbf{S}) (\hat{\mathbf{b}}^T \mathbf{S})^T \\ &= 2\hat{\mathbf{b}}^T (\mathbf{R} \mathbf{b} + \mathbf{n}) - \hat{\mathbf{b}}^T \mathbf{R} \hat{\mathbf{b}} \end{aligned} \quad (6)$$

where $\mathbf{n} = \int_{T_s} S_k(t) n(t) dt$, and $\mathbf{R} = \mathbf{S} \mathbf{S}^T$ is an auto and cross correlation matrix. We define $y = \mathbf{R} \mathbf{b} + \mathbf{n}$, which can be treated as the output of the matched filter (MF). Thus, we treat $\Omega(\hat{\mathbf{b}})$ as the objective function.

3.3. Selection and Crossover

In order to evolve the population, some excellent individuals will be chosen to constitute a future population for reproduction. The fitter individuals with better genes are more likely to be selected to

produce the offspring individuals. Thus, the rule of selection is based on their fitness or OF value. The selection probability of the p th individuals is

$$P_p = \frac{\Omega(\hat{\mathbf{b}}_p^{(g)}) - \Omega_w^{(g)} + 1}{\sum_{p=1}^P (\Omega(\hat{\mathbf{b}}_p^{(g)}) - \Omega_w^{(g)} + 1)} \quad (7)$$

where $\Omega(\hat{\mathbf{b}}_p^{(g)})$ is the OF value of the p th individuals at the g th generation, and $\Omega_w^{(g)}$ is the worst OF value at the g th generation.

Crossover is the operation by which the selected individuals exchange their genes to produce pairs of offspring. Concretely, the crossover operation randomly chooses one cutting point or many cutting points and exchanges the binary strings of individuals before or after the cutting point(s).

3.4. Proposed complementary error function mutation (CEFM)

In this part, we present a new mutation operation, namely complementary error function mutation (CEFM). In the proposed CEFM procedure, a mutation probability $p_m^{(i,j)}$ which is relative to a signal noise rate (SNR) from i to j is defined. It can be calculated with the help of a complementary error function

$$\text{erf c}(x) = \frac{2}{\sqrt{\pi}} \int_x^\infty e^{-t^2} dt, \quad x \geq 0 \quad (8)$$

Fig. 2 is an illustration of the mutation probability $p_m^{(i,j)}$ for BPSK modulation. A vertical dashed line separates -1 and 1, and the Gaussian distribution $N(0, \sigma^2)$ is centered to the left side of that line, namely at the position of -1. Here, σ^2 is noise variance at a specified SNR level. The mutation probability from -1 to 1 (i.e. $p_m^{(-1,1)}$) is proportional to the shaded area in Fig. 2. It can be obtained by

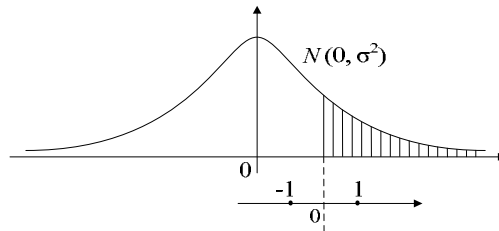


Fig. 2 Illustration of the mutation probability

$p_m^{(-1,1)}$ based on a complementary error function (CEFM) for BPSK

$$p_m^{(-1,1)} = \frac{1}{2} \text{erf c}\left(\left|\frac{-1-1}{2}\right| \cdot \frac{1}{\sigma^2}\right) = \frac{1}{\sqrt{\pi}} \int_{\frac{1}{\sigma^2}}^\infty e^{-t^2} dt \quad (9)$$

Similarly, we can obtain

$$p_m^{(1,-1)} = \frac{1}{2} \text{erf c}\left(\left|\frac{1-(-1)}{2}\right| \cdot \frac{1}{\sigma^2}\right) = \frac{1}{\sqrt{\pi}} \int_{\frac{1}{\sigma^2}}^\infty e^{-t^2} dt \quad (10)$$

We find that $p_m^{(-1,1)} = p_m^{(1,-1)}$, and thus we define $p_m = p_m^{(-1,1)} = p_m^{(1,-1)}$ as the CEFM probability for BPSK modulation.

3.5. Elitism and generation iteration

The operation of elitism copies a small part of the best parent individuals, and replaces the worst offspring. Then the genetic operations above are cycled from one generation to another, until the generation index g reaches its maximum G . If the number of generations G and/or the population size P are large enough, the final results of GA MUD for K users approach the optima.

4. Simulation results

Simulations were conducted to evaluate the performance of our proposed CEFM-GA DA MUD for a multiuser UWB communication system in which direct sequence was employed. The UWB pulse was the second derivative of Gaussian pulse. There were four users in the UWB system, and the length of the spreading code was 31 (Gold codes were used). The details of the system parameters are summarized in Table 1.

Table 1 Summary of system parameters

Config	Parameter	Value
GA	Population size	$P=15$
	Generation No. (CEFM-GA)	G is varied
	Generation No. (accessorial detector of CEFM-GA DA)	$G_1 = \alpha G$ ($\alpha = 0.3$)
	Generation No. (accessorial detector of CEFM-GA DA)	1
	Generation No. (the second cycle of CEFM-GA DA)	G' is varied
	Selection method	Fitness-based
	Crossover	Uniform crossover
	Mutation	CEFM
UWB	User No.	$K = 4$
	Modulation	BPSK
	Channel model	lognormal fading CM1
LDPC	Code rate	1/2
	Iteration No.	15
	Codeword Length	512 bits

In this article, we consider the UWB channel models (CM) of IEEE 802.15.3a CM1 (line-of-sight (LOS) channel characteristics) [5] in which the channel impulse response (CIR) for each user is randomly selected from 200 channel realizations.

Fig. 3 compares the BER performance of different MUDs for the lognormal fading UWB system in CM 1, where $K = 4$ users and a processing gain of $NS = 31$ are supported. Our proposed CEFM-GA are much better than SIC, PIC (50 stages) and conventional GA without CEFM. Specifically, G is the number of generations in CEFM-GA, and G' is the number of generations for the second cycle of detection in CEFM-GA (as $G = 10$, the number of generations of the major detector $G_1 = \alpha G = 0.3 \times 10 = 3$). The

CEFM-GA with $G' = 20$ or 30 can obtain much better BER performance than the Conventional GA with $G = 10$.

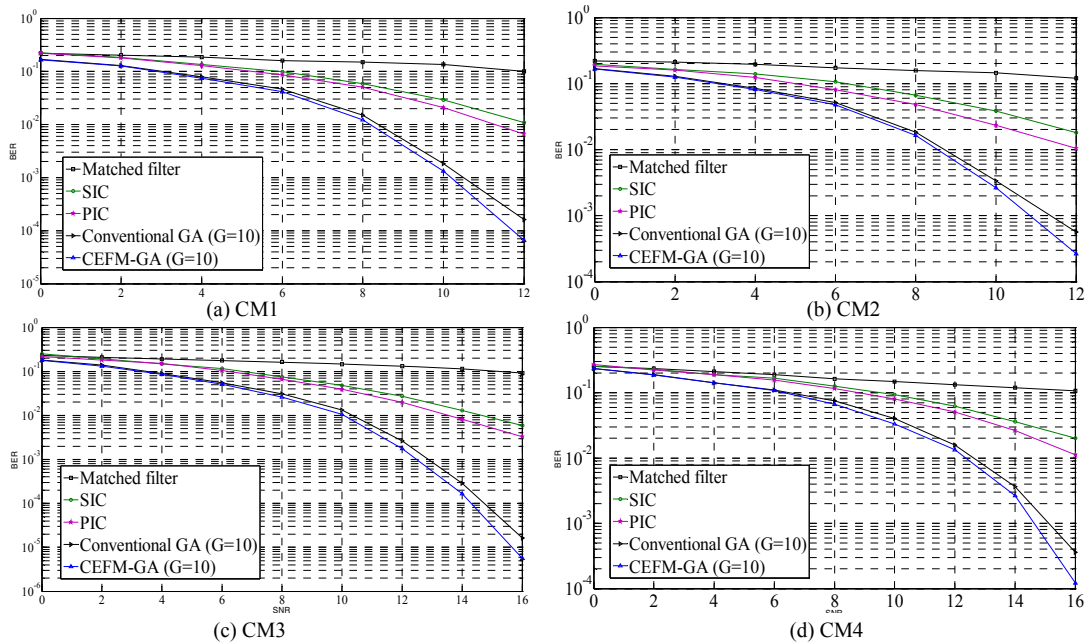


Fig. 3 BER performance of different MUDs for a lognormal fading UWB system

5. Conclusions

In this paper, we propose a MUD with a novel GA based on complementary error function mutation (CEFM) for UWB systems. We describe the principles of our proposed CEFM-GA, give an objective function (OF) for the CEFM-GA, and analyze their algorithms for the improvement of BER performance. Simulation results showed a significant performance gain can be achieved by employing the proposed CEFM-GA compared with successive interference cancellation (SIC), parallel interference cancellation (PIC), conventional GA.

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